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# A COUNTER GATING CIRCUIT FOR ACOUSTIC EMISSION MONITORING OF STRUCTURES CRACKING UNDER REPETITIVE ALTERNATING LOADS

by

M.R. Kindermann



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# A COUNTER GATING CIRCUIT FOR ACOUSTIC EMISSION MONITORING OF STRUCTURES CRACKING UNDER REPETITIVE ALTERNATING LOADS

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## SUMMARY

A circuit for gating the input to an electronic counter used in the acoustic emission monitoring of cyclically loaded propagating cracks is described. The circuit ensures that acoustic emission signals registered by the counter arise principally from propagating cracks and that the counting of extraneous signals such as those occurring as a result of rubbing and fretting of contacting surfaces are minimised.


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## 1. INTRODUCTION

Acoustic Emission (AE) signals generated by structures undergoing cyclic loading arise from several simultaneous processes. If the structure being monitored is subject to stresses near the yield point of the material, emissions due to cracking are likely to occur. Thus, signals due to cracking are expected at, or near to, the positive (tensile) peak of the loading cycle. Emissions occurring at lower stresses are mainly due to machine noise and the rubbing and fretting of contacting surfaces. These noise signals often arise at the site of fasteners and near negative (compressive) peaks where crack surfaces can come into contact. These extraneous signals need to be minimised in the recorded AE data. Consequently, emissions occurring at or near the positive peak of the loading cycle give the most reliable and unambiguous indications of fatigue crack growth. This note describes a gating circuit which only allows recording of acoustic emissions at or near to the peak tensile load.

## 2. ACOUSTIC EMISSION (AE) MONITORING

The frequency band of acoustic emission is dependent on the material composition of the cracking component, and for aluminium alloys is centred at about 50 kilohertz. Transducers with a fundamental resonance centred in the AE frequency band are basically piezo-electric accelerometers without the mass placed on the upper surface of the piezo-electric element. These accelerometers are acoustically coupled to the surface of the test piece with a viscous fluid.

The response characteristic of a typical AE transducer is approximately Gaussian with an effective 'Q' factor of about 5. A convenient definition of Q for this application is

$$Q = \frac{f_0}{f_2 - f_1} \text{ where}$$

$f_0$ is the resonant frequency of the transducer and $f_1$ and $f_2$ are the lower of upper half-power frequencies respectively, where the signal power falls to one half its value at the central resonant response peak; (i.e. three decibels below the peak). If increased 'sharpness' of the overall response is required, then this may be achieved by passing the received signal through cascaded, tuned amplifying stages prior to it being monitored by the counter.

Having defined and established the system for the detection of the AE signal, we must now define the test conditions under which such signals will be monitored.

## 3. TEST CONDITIONS

Conditions applying to a typical test are as follows:-

An airframe was to be monitored for cracking under simulated flight loading. Loading sequences, generated by computer, were applied electro-hydraulically to selected regions of the airframe. These loading sequences were approximations to actual in-flight loads obtained by strain-gauge measurements on an aircraft in flight. The loading sequence comprised waves of various amplitudes, periods and waveform (harmonic content).

A diagram representing these conditions is shown in Fig. 1 where the counter is activated at point A and disabled at point B. Thus it is seen that a circuit was required that would activate the AE counter at a particular amplitude $V_A$ of rising load and disable it at a second predetermined amplitude $V_B$ under falling load. These conditions are met in the circuit to be described.

## 4. THE GATING CIRCUIT

A block diagram of the gating circuit is shown in Fig. 2. The voltage analogue of the load function $e_i$ is applied simultaneously to two voltage comparators and a differentiator. The voltage comparator "start" selects the voltage amplitude $V_A$, and the "stop" selects the voltage amplitude $V_B$.

The differentiator senses the slope of the waveform, giving an output proportional to its negative differential coefficient. The circuit logic is designed to:

(i) direct $V_A$ and positive slope information to the start pulse output.

(ii) direct $V_B$ and negative slope information to the stop pulse output.

(iii) constrain the negative slope and $V_B$ signals to follow a trigger from the $V_A$ and positive slope condition.

In specific terms, the circuit functions as follows:

The output of the differentiator is passed to two comparators denoted ' - ' and ' + '. The comparator ' - ' is arranged so that when the differentiator output falls below -50 millivolts, it fires, and produces a logic 1 output; similarly comparator ' + ' produces a logic 1 output when the differentiator output rises above +50 millivolts. The ± 50 millivolt levels were chosen as it was found that these values are those closest to zero volts which gave stable and reliable operation of the comparators. The outputs from the 'START' comparator and the ' - ' comparator were 'AND' gated together to provide a trigger signal for multivibrator 1 which provides the 'start' pulse. Similarly, outputs from the 'STOP' and ' + ' comparators were AND gated together at A2 to trigger multivibrator 2 to provide the 'stop' pulse. When multivibrator 1 fires, it also activates a latch comprising a type 7476 flip-flop. This latch controls the third input to 'AND' gate A2, enabling it to switch the $V_B$ and negative slope information to multivibrator 2 when the latch is activated. Thus, multivibrator 2 is prevented from operating unless the latch has been activated (triggered). When the load function analogue falls to $V_B$ with a negative gradient and the latch has been activated, multivibrator 2 generates a 'STOP' pulse and resets the latch. Thus a 'STOP' pulse is prevented from being generated unless a 'START' pulse had immediately preceded it. Such a condition could arise as shown graphically at point C on Fig. 1. It will be noted that the 'START' and 'STOP' outputs are buffered by inverters prior to being made input to the counter.

This was found to be necessary to obviate erratic triggering of the counter occurring as a result of it loading the multivibrator outputs.

The circuit diagram depicted in Fig. 3, shows that the 7400 family of logic devices has been used. Other logic families, such as the 74LS00 series of low power Schottky devices, could be substituted if desired with appropriate changes to the circuit elements (resistors, capacitors) as required. However, the 'START' and 'STOP' outputs may require buffering with devices selected from the 7400 family, depending on the counter used, the length (capacitance) of the cables used etc, in order to provide the low incremental source impedance and driving capability (fan-out) necessary for reliable triggering of the counter.

Design features, found necessary for reliable operation, are as follows:-

The output circuit of the differentiator has two zener diodes connected in series with opposing polarity, together with a 560 ohm current limiting resistance, to limit the voltage excursions generated by the differentiator to about ±9.8 volts. This was found to be necessary to prevent the large voltage excursions generated by the differentiator from overloading the inputs to the comparators.

All four voltage comparators were fitted with hysteresis networks at their positive inputs. This was necessary to stabilize operation by improving noise immunity.

The trigger inputs to the two multivibrators were by-passed with 0.33 microfarad capacitors to prevent spurious triggering by random noise.

## 5. DISCUSSION

This circuit was used in conjunction with a General Radio Model 1192B counter and a Hewlett Packard Model 562 printer, the printer being used to record the data from the counter for each successive test cycle. The printer may be exchanged for a modern computer-based data acquisition system, suitably interfaced to the counter if desired.

The system gave reliable performance when monitoring an airframe undergoing simulated flight loading. The onset of structural cracking was successfully indicated as later verified by radiography after cracking had proceeded to a point where the resolution of the radiographic technique enabled the cracks to be detected.

No attempt was made to use the equipment in a crack-location mode; such testing would require several transducers together with their associated circuitry. However, this circuit could be adapted to such an application and, for such testing, it is suggested that a separate gating circuit be used with each transducer rather than resorting to multiplexing, as gating times could overlap and thus lead to loss of data.

## ACKNOWLEDGEMENT

The author wishes to express his appreciation to Mr D.A. Olley, of N.D.I.S.L., R.A.A.F Amberley, Queensland, who carried out acoustic emission monitoring of an airframe under cyclic loading using this circuit; and who also made periodic radiographic inspections of the airframe resulting in verification of the initiation and progression of cracking.

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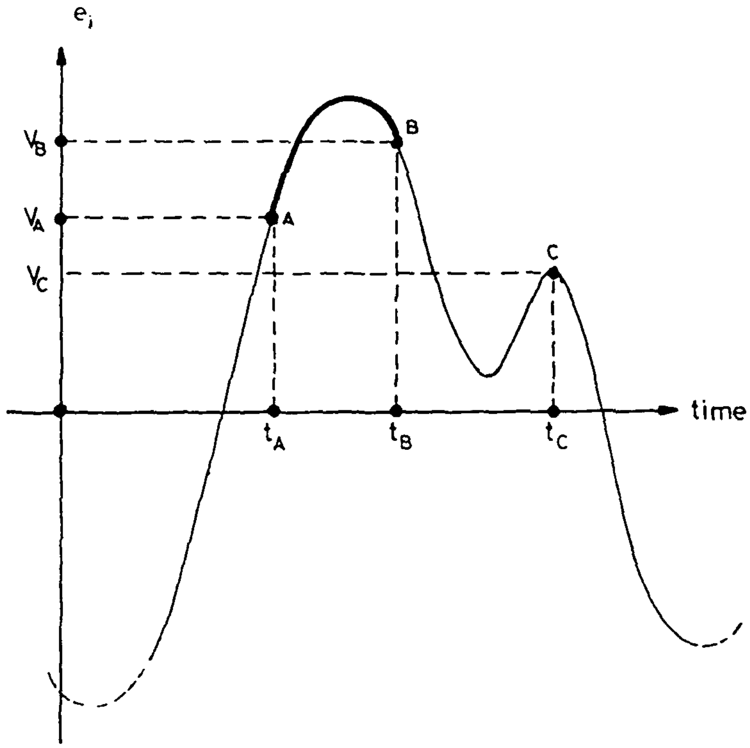


Fig. 1

Representation of Loading Sequence

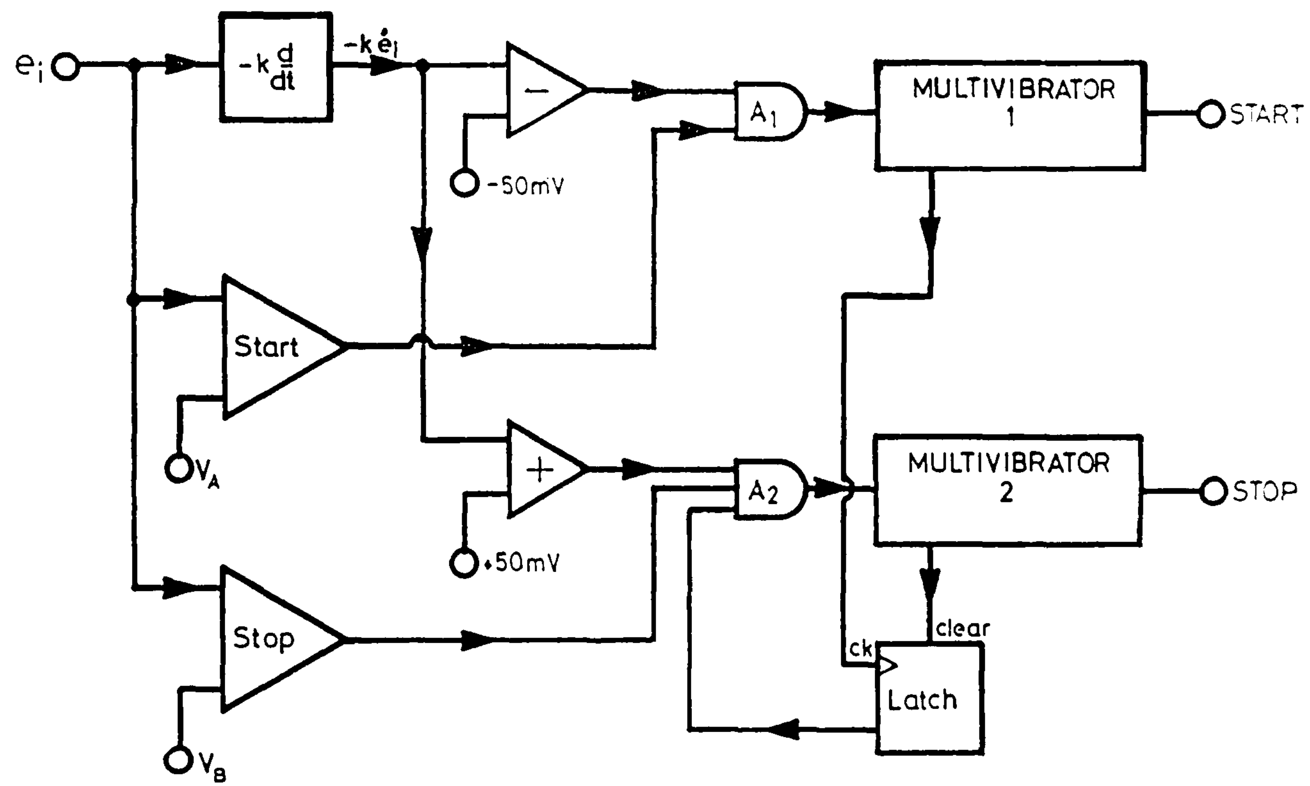


Fig. 2

Block Diagram

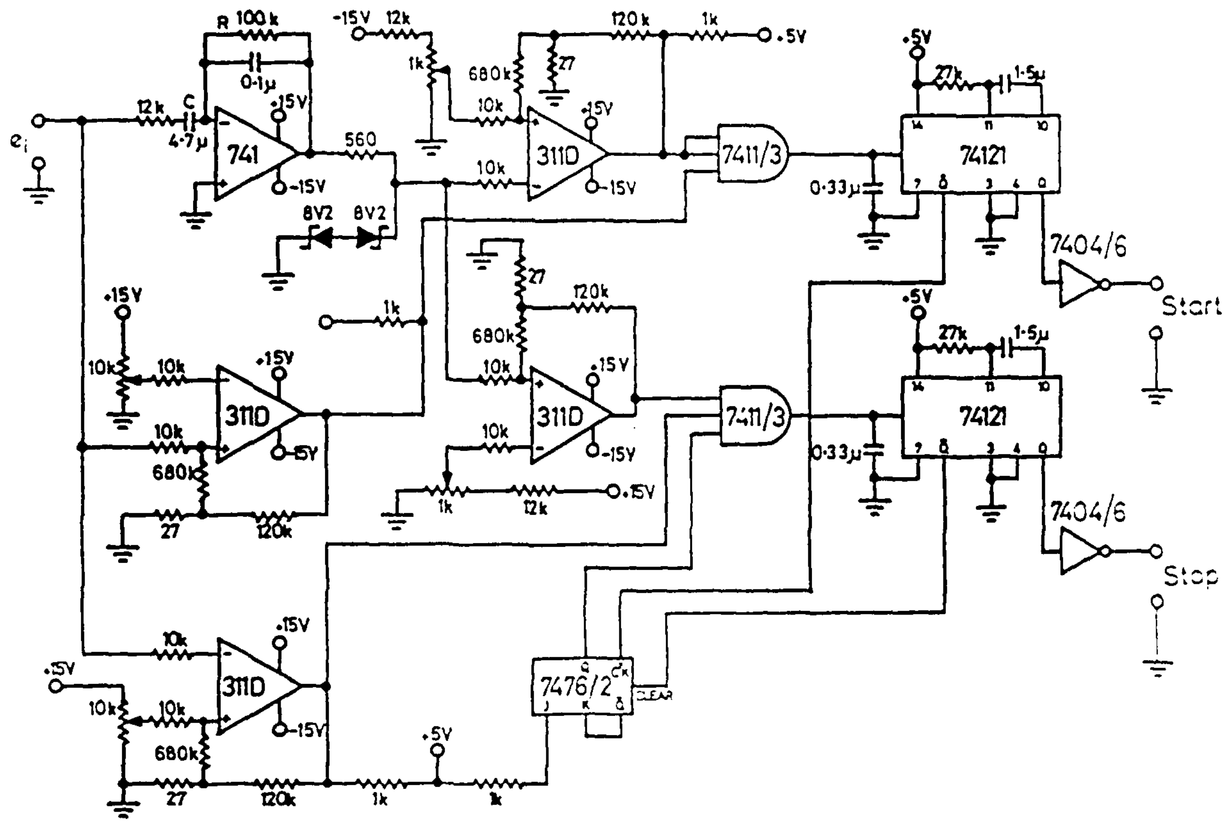


Fig. 3

Circuit Diagram

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